Weight reduction is again a priority across the industry, as strict new regulations push for greater vehicle efficiency/CO₂ reduction in the U.S. and Europe. From the smallest fasteners to entire vehicle architectures, engineers are wringing excess ounces out of new components and systems, while looking for new ways to lighten up existing designs.

The benefits of lightweighting correlate directly to greater fuel economy as well as to improved vehicle dynamics. Studies have shown that every 10% reduction in vehicle weight can yield 5 to 8% greater fuel efficiency. Dropping 150 lb (68 kg) on average gives an extra mile of driving range per gallon of fuel consumed. In terms of its effect on carbon emissions, reducing vehicle weight by 220 lb (100 kg) brings a CO₂ reduction of up to 12.5 g/km.

Automakers have made mass reduction part of their vehicle development strategies going forward, while ensuring no sacrifices in safety or durability. Nissan, for example, has pledged to slash average vehicle curb weight by 15% through 2015. Ford, as part of its corporate goal to boost fleet fuel economy 40% by 2020, aims to reduce vehicle weight by 240 to 750 lb (109 to 340 kg), depending on the model.

A daunting task for every OEM will be dealing with “mass creep”—the tendency to make each new-generation model heavier than its predecessor. Mass creep is caused by adding new features, safety equipment, and emissions-control content. Consumers also expect new models to be larger and more commodious than the ones they replace.

“Offsetting extra pounds added by new features definitely is a challenge,” noted Matt O’Leary, Chief Engineer on Ford’s 2009 F-150. He said it takes great attention to detail to achieve mass parity between vehicle generations. Genuine mass reductions are a tougher task, one that O’Leary’s team accomplished. The F-150 base model, for example, arrived approximately 100 lb (45 kg) lighter than the equivalent ’08 model even though it is larger and better equipped.

Last year’s all-new Mercedes-Benz C-class sedan was that company’s first new model that was not heavier than its predecessor, despite growing in size and feature content. Ditto for the current Mazda2, which last year came in 220 lb (100 kg) lighter than the previous model.
Today’s mass-reduction efforts likely will not be as swift or dramatic as those that transformed the U.S. passenger-car fleet 30 years ago. Back then, the domestic makers launched bold vehicle-downsizing programs to meet the new CAFE regulations. Their massive shift from body-on-frame to unibody structures, from V8 engines to V6s, and from rear-wheel drive to front drive, was combined with smaller platforms—wheelbases were shortened by an average 7 in (178 mm).

The net result was an average 1000-lb (454-kg) reduction in U.S. passenger vehicle curb weight, with an equally sharp jump in fuel efficiency. (Critics claimed it also compromised occupant safety.) Suppliers were incentivized to aid the cause: In the early 1980s, General Motors paid back its suppliers $1 for every pound trimmed from their products.

A recent shift in the North American fleet mix is again precipitating a drop in average curb weights. It is due to the collapse of the full-size SUV segment, the rise in unibody crossovers, and a falloff in non-commercial pickup sales, explained Dick Schultz, Project Consultant with Ducker Worldwide, which analyzes automotive materials trends and technologies.

“In the past five years, we’ve lost a whole lot of real big vehicles, as American consumers traded their 14-mpg, 5000-lb (2268-kg) Cadillac Escalades for 24-mpg, 4000-lb (1814-kg) Buick Enclaves or even smaller crossovers,” said Schultz, a veteran metallurgist.

In 2004, average U.S. market curb weights peaked at 4018 lb (1823 kg). Schultz noted, with 42% of production being body-on-frame vehicles. The average 2009 U.S. market vehicle weighs 3755 lb (1703 kg), with only 25% of the production mix being full frame. The resulting average weight reduction in recent years: about 260 lb (118 kg). And as the accompanying graph reveals, the decline in vehicle mass is expected to continue through 2020.

“In the next decade, we won’t see the average unibody vehicle getting too much smaller—the U.S. will pretty much continue to be a C- and D-segment market although some makers will bring in A- and B-class cars for specific regions,” Schultz explained.

North America, it should be noted, offers the most opportunity for significant mass reductions due to its traditional large-vehicle fleet mix.

Given those assumptions, it will be up to designers, engineers, and materials experts to further reduce average vehicle mass to the 3500-lb (1588-kg) average forecast for the 2020 North American fleet by Ducker Worldwide. That is a drop of about 255 lb (116 kg) from the ‘09 average.
Aluminum’s success

For automakers, the path to vehicle mass reduction requires a systems strategy, say experts. “It’s a delicate balance matching the overall vehicle weight against improved powertrain efficiencies, the body, and the interior,” said Matthew Zaluzec, Ford’s Manager of Materials Research.

The lightweighting technologies currently in Ford’s labs will apply to vehicles from 2012-25, he said. “We’re not inventing new materials, but rather applying the right materials that are cost competitive,” Zaluzec explained.

The system and materials mix Ford has adopted for its vehicle mass-reduction plan centers on using increasing percentages of advanced high-strength steels (AHSS) for the body-in-white. Aluminum and magnesium will be used for closures and, depending on the vehicle program, for various structural and chassis applications such as magnesium radiator supports and suspension systems. The mixed-material strategy is fundamentally similar to those of other major OEMs.

“Lightweighting is never for free,” Zaluzec asserted. “We’ve done aluminum-intensive vehicles, including the current Jaguar XJ8 and the Ford GT super car. There’s a major up-front investment in manufacturing process,” he said. There is also an ongoing debate about value proposition.

On the merits of its curb weight alone, the XJ8 appears to make a strong case for going the all-aluminum route. The 2009 base model, its body-in-white a matrix of 5000-series-alloy stampings, castings, and extrusions, and 6000-series alloy exterior panels, tips the scales at 3770 lb (1710 kg). That’s 580 lb (263 kg) lighter than the base Lexus LS460, a predominantly steel-bodied competitor with comparable powertrain specifications. It is also the lightest sedan in its segment.

However, the Jag’s 16/25 mpg U.S. EPA fuel economy rating is essentially identical to the Lexus’ 16/24 mpg. In an era where even a luxury vehicle’s CO₂ footprint increasingly ranks near the top of purchase considerations, a costly and complex rivet-bonded aluminum body shell might present a challenging business case.

Not if you are Audi, however. As the industry’s volume leader in aluminum-structure vehicles since the breakthrough A8 in the 1980s, Audi has pushed ahead with its lightweight spaceframe technology, now used on the TT, TT Roadster, A8, R8, and Lamborghini Gallardo.

The latest ASF (Audi Space Frame) architecture introduced on the 2008 TT models is an aluminum/steel hybrid that cuts weight by around 100 kg (220 lb) compared to the previous all-steel structure. The company estimates the reduced weight will decrease fuel consumption by 0.7 mpg.

The construction features aluminum extrusions and castings, with a mix of sheet-aluminum and steel exterior panels and closures, and steel structural elements. The frame sections vary in type, size, and thickness depending on load, and although the side sills on the TT Coupe and Roadster are visually similar aluminum extrusions, the Roadster’s sill features thicker internal ribbing to provide the added torsional rigidity needed by the open-top car.

There is also a steel bulkhead behind the Roadster’s seats that joins the steel subframe that extends from the B-pillar to the rear of the car. The TT Coupe and Roadster both use steel doors with extruded-aluminum side-impact beams. The Roadster also employs a steel decklid while the Coupe uses aluminum. The remaining Class-A exterior panels are stamped aluminum sheet.

The Coupe body shell weighs 455 lb (206 kg), of which 309 lb (140 kg) is aluminum—65% of the total by weight. High-strength steel makes up the remaining 32%. Audi engineers claim static torsional rigidity is increased 66% compared with the previous structure. The steel content in the rear of the cars is also used to balance weight distribution, for improved handling.

To join the dissimilar metals, Audi continues to invest in the sophisticated, costly tools and processes to make it happen in volume. The processes include punch riveting and adhesive bonding, which eliminates galvanic corrosion.

Audi is readying the next-generation mixed-metals body architecture for its MY2011 A6 platform. Dubbed ASF-II, it will offer a claimed 50% reduction in body shell weight and 50% greater structural rigidity compared with the current A6. Further use of steel reinforcements with new joining processes are expected.

The company is committed to applying ASF-II up and down the product portfolio to increase manufacturing scale and thus lower investment costs. Lessons learned on the high-cost A2 program will be useful in driving the technology down market into the A3 and even smaller future models. And ASF-II applied to the large Q7 crossover SUV potentially could save up to 660 lb (300 kg).

The use of aluminum sheet for clo-
Investigating aluminum con rods

The push for greater vehicle efficiency has advanced materials researchers exploring light-metals applications in various powertrain reciprocating components. Forged aluminum connecting rods were used successfully for 50 years in mass-produced British motorcycle engines and are popular in drag-racing circles. Today they are under development at Peak, the supplier of aluminum cylinder liners for Honda V6 engines.

According to Peak North America President Bill McCall, con rods forged in Peak's proprietary Dispal S232 alloy offer a 1-lb (0.5-kg) mass reduction per unit—6 lb (3 kg) total in a six-cylinder engine—compared to conventional powder-metal steel con rods. Concerns regarding aluminum’s fatigue limit in this high-stress application are addressed in the component geometries and the Dispal material properties.

McCall noted that techniques for precision-fracturing (cracking) the big end are being investigated. Peak prototyped aluminum con rods for Honda’s recently canceled V8 engine program.

Lindsay Brooke

Sure panels continues to grow.

According to The Aluminum Association, the number of closure programs globally has risen from 231 in 2006 to 263 programs in 2009, a 14% gain. Hoods and decklids offer a 40 to 50% weight savings over the comparable steel part—and being large panels they are logical targets for cutting weight.

In 2009, a record 22.3% of vehicle production will have an aluminum hood. “Every year, aluminum gains about one market-share point in hoods,” noted Schultz. “We think that application will be 35% by 2020.”

“Approximately half of Ford vehicles already have aluminum hoods and more are on the way,” commented Zaluze. “Now we’re doing R&D on aluminum doors—a traditional steel application,” he revealed. “I won’t say when we’re going to put them into production, but they’re part of our overall weight-reduction strategy.”

As a percentage of average vehicle curb weight, aluminum reaches an all-time high at 8.7% in 2009—about 326 lb (148 kg) of all product forms per North American light vehicle. Steady growth is expected in suspension and driveline components, along with a final assault on the remaining 25% of engine cylinder blocks still in cast iron. Experts expect aluminum’s percentage of average curb weight to exceed 10% in 2020.

“Powertrain improvements alone will not be enough to get automakers to the necessary fuel economy improvements that are going to be expected,” said Buddy Stemple, Chairman of The Aluminum Association’s Auto and Light Truck Group. “With the current state of the industry, aluminum will be significant in key automotive decisions concerning fuel economy and mass reduction overall.”

To Stemple’s point, Toyota will launch the first production aluminum-based wiring harness, on its MY2011 Yaris subcompact. The harness, to be supplied by Sumitomo Electric Industries, will be nearly 40% lighter than conventional copper wire and is expected to be less expensive. That is a potential boon to B-segment and smaller vehicles that inherently are not laden with excess mass. However, it comes with a compromise—the aluminum harness also will be up to 25% larger in diameter than a copper-based harness.

AHSS hits prime time

Charging fast and furiously into the body structure arena are AHSS, including martensitic, boron, and dual-phase materials. And they get materials gurus like Ford’s Zaluze plenty excited over their potential.

“We’re talking 500 MPa and above in tensile strength for some of them,” Zaluze exclaimed. “AHSS allows us to take up 15% of the weight out of a steel body structure while optimizing the overall body architectures and really improving the strength-to-weight ratio of crash-critical areas such as rockers, sills, pillars, crossmembers, and bulkheads.”

The 2009 Acura MDX/Honda Pilot, BMW X6, the GM Lambda crossovers (Chevrolet Traverse/Buick Enclave/GMC Acadia/Saturn Outlook), Honda Civic, and Nissan Altima all use a high proportion of AHSS in their bodies-in-white.

In a study due to be presented next month at the American Iron and Steel Institute (AISI)’s “Great Designs in Steel” meeting, Ducker Worldwide’s Dick Schultz forecasts 250 lb (113 kg) of AHSS and 20 lb (9 kg) of aluminum will replace 346 lb (157 kg) of mild steel and various bake-hardenable and high-strength steels for upcoming body, bumper and closure applications.

“In the last two years, AHSS use has grown at 16.5% per year,” he reported. “While some of that growth is due to the recent shift to unibody, as those vehicles generally use more advanced steels than do body-on-frame vehicles—although the new F-150 uses quite a bit and the Dodge Ram uses some—we expect that growth to continue at around 10% per year.”

The AHSS grades are more expensive than conventional high-strength types, and their value relative to aluminum is determined by formability, Schultz explained. It also depends on part geometry. Some of the black-metal parts are complex and very difficult to form, he said. Steel makers are seeing a shift to martensitic and boron bumper beams because the auto industry is learning how to engineer and produce these parts in AHSS.

“They have to hot-stamp the boron and roll-form the martensite,” Schultz noted. “And they’re starting to compete